STUDIES ON THE FADING OF THE RADIO WAVES RETURNED FROM THE SPORADIC E-REGION OF THE IONOSPHERE

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ABSTRACT. In some of the studies with vertical pulsed transmission, the blanketing type and the q-type of E_s have been observed. The wind-type of E_s having a quickly varying top frequency has also been found. Using a horizontal dipole as the receiving aerial, the fading records of the E_s-echoes have occasionally shown a double-trace on the moving film for both the first and the second orders of reflection. On rare occasions, an additional trace has also been observed in this region. A tentative explanation of the double or triple trace has been suggested.

Using the selective aerial for the reception of one or the other of the two magneto-ionic components, the fading records of a *single* downcoming wave from the sporadic E-region have been taken on the moving film. The statistical distribution of the amplitude has shown that usually at noon hours, both the Rayleigh and the Rice types of distribution occur, whereas during morning, evening and early night hours, when the reflection is from the E_s-region, there have been other types of amplitude distribution. Of these, the most frequent type has shown usually two maxima in the amplitude distribution curve. The double-peak or the so-called M-type distribution suggests the existence of two simultaneous and independent super-imposed processes. It is likely that the double-peak is associated with the occurrence of a double-layer in the sporadic E-region.

Typical ν_T-distribution curves have also been shown. The rms line-of-sight velocity of the irregularities in the E_s-region has been calculated.

INTRODUCTION

In the present paper, the results of some of the investigations with vertical pulsed transmission on the echoes from the sporadic E-region carried out at Calcutta on different frequencies has been presented. With regard to the different types of sporadic E, the blanketing type and the q-type of E_s have been observed at times. It has also been possible to observe the wind-type of E_s having a rapidly varying top frequency. A major part of the work has been devoted to the recording of random fading patterns for the downcoming radio pulses reflected from the sporadic E-region. Usually frequencies greater than the critical penetration frequency of the normal E-layer have been employed. Using a horizontal dipole as the receiving aerial, it has been occasionally found that the random fading record on the moving film has a double-trace in the sporadic E-region.

for both the first and the second orders of reflection. On a few records, an additional trace on the moving film has also been observed.

Some statistical studies of the single downcoming wave returned vertically from the sporadic E-region have also been incorporated in the paper. To obtain a single downcoming wave, the selective aerial system for circular polarization, first designed and employed by Ratcliffe and White (1933) for the study of the polarization of the downcoming wave, has been mostly used. For frequencies greater than the critical penetration frequency of the normal E-layer, the ordinary and the extraordinary components are expected to be circularly polarized. In reality, however, there is a departure from circular polarization and the suppression of one or the other component is not complete. Since the extraordinary component usually suffers in the day-time a much larger absorption in the sporadic E-region than the ordinary component, the use of the selective aerial system of Ratcliffe and White with the receiver would give for all practical purposes, a single ordinary component. When, however, the two magneto-ionic components are of comparable magnitude, and they are unresolved, a rhythmic or periodic fading (Appleton *et al*, 1947) under conditions of gradually increasing or decreasing electron-desnity in the ionosphere, has been at times observed, as expected. In the analysis of the fading records, the parts showing only random fading have been utilized. It may be noted that periodic fading can be avoided by observing *visually* the fading pattern on the CRO screen (Mitra, 1949).

The statistical studies have shown the Rayleigh (1899) and the Rice (1944) type of amplitude distribution along with other types. Of the other types, the most frequently observed type has shown two maxima in the amplitude distribution curve. This double-peak type was first observed by Das Gupta and Vij (1960) for the reflection from the F-layer and was called the M-type. Such double-peak amplitude distribution was also obtained by Kushnerevsky and Zayarnaya (1962) in the case of F_2-reflection. The time-analysis of the random fading records of the single downcoming wave returned from the sporadic E-region has also been carried out, enabling the determination of the rms line-of-sight velocity of the irregularities in the sporadic E-region.

Statistical analyses of random fading of a single downcoming radio wave had previously been carried out by various investigators, viz, Rice (1944, 1945), Ratcliffe (1948, 1956), Mitra (1949), McNicol (1949), Alpert (1948), Subhadramma (1955, 1958) Schwentek (1962), Yeh and Villard (1962), Rao and Rao (1964), Sen and Khastgir (1965) and others.

THEORETICAL CONSIDERATIONS

Amplitude analysis of the random fading records : A major cause of random fading of a single downcoming radio wave returned from the ionosphere is due to the random motion of the ionospheric irregularities which would scatter in a random manner the radio waves incident on them. The resultant amplitude is considered as due to a large number of scattered components from a series of diffracting centres distributed at random, both in space and time, in the ionospheric region. Considering a large number of scattered components of random amplitude and phase, the probability of occurrence of the resultant amplitude at any instant would be obtained from the well-known expression given by Rayleigh (1899).

The Rayleigh probability distribution at any instant is given by :

$$P(r) = \frac{r}{\psi} \exp\left(-\frac{r^2}{2\psi} \right) \qquad \dots \quad (1)$$

where r is the resultant amplitude of the scattered components and ψ is a term which is half of the mean square value of the amplitudes.

If the rms value of the amplitudes of the scattered components be denoted by R, then $\psi = \frac{\overline{r^2}}{2} = \frac{R^2}{2}$.

The Rayleigh expression can then be expressed as :

$$P(r) = \frac{2r}{R^2} \exp\left(-\frac{r^2}{R^2} \right) \qquad \dots \quad (2)$$

If now the most probable amplitude (i.e., the amplitude for which $P(r)$ is maximum) be represented by r_m, then it can be shown

$$r_m^2 = \psi = \frac{R^2}{2} \qquad \dots \quad (3)$$

The Rayleigh distribution may then be written as :

$$P(r) = \frac{r}{r_m^2} \exp\left(-\frac{r^2}{2r_m^2} \right) \qquad \dots \quad (4)$$

Writing (4) in the form

$$\log \frac{P(r)}{r} = \log\left(\frac{1}{r_m^2} \right) - \frac{r^2}{2r_m^2} \qquad \dots \quad (5)$$

it is evident that the plot of $\log \frac{P(r)}{r}$ against r^2 would be a straight line, the slope of which would give $\frac{1}{2r_m^2}$ and the intercept $\log\left(\frac{1}{r_m^2} \right)$.

If in addition to the scattered components from the irregularities in the ionospheric layer, there is a steady specularly reflected component, then it is evident that the observed probability distribution of amplitude at any instant at the receiving point would no longer be given by the Rayleigh formula. It was shown by Rice (1944, 1945) that under such condition, the probability distribution of the amplitude would be given by

$$P(r) = \frac{r}{\psi} \exp\left(-\frac{r^2+B^2}{2\psi}\right) I_0\left(\frac{rB}{\psi}\right) \quad \cdots \quad (6)$$

Here B is the amplitude of the steady component, I_0 is the Bessel function of zero order and imaginary argument and the other symbols have the same meaning as in the Rayleigh expression.

When $r \approx B$, the most probable amplitude in the Rice distribution would be given by :

$$r_m^2 = B^2 + \frac{R^2}{2} \quad \cdots \quad (7)$$

From the curves showing the probability distribution of amplitude in an experimental record, it is possible by comparison with the curves drawn from the theoretical formulae, to estimate the ratio of the amplitude of the steady reflected component to the rms value of the resultant amplitude of the scattered components. McNicol (1949) gave a series of curves for the various values of $b = \frac{\sqrt{2}B}{R}$. It was shown that when $b < 1$, $P(r)$ would follow approximately a Rayleigh distribution and when $b > 3$, the distribution would be almost Gaussian.

(b) *Time analysis of the random fading records.*

If we divide the time of the fading records into a series of equal intervals of time, τ, and if v_τ represents the change in amplitude during each such time-interval, then assuming that each of the ionospheric irregularities scatters equal amount of power and has the line-of-sight velocities distributed about the rms velocity according to the Gaussian law, the probability distribution of the amplitude-changes over the time-interval, τ, can be found. Following a procedure worked out by Fürth and Macdonald (1947), who analysed the radio noise which pass through a Gaussian band-pass filter, Ratcliffe showed that when τ is small, the probability distribution $P(v_\tau)$ would be given by :

$$P(v_\tau)dv_\tau = \frac{1}{\sqrt{\pi}} e^{-x^2}\, dx \quad \cdots \quad (8)$$

where $x = \frac{v_\tau}{2\pi\sigma\tau R}$ and σ is the standard deviation of the Gaussian velocity distribution. With the help of (8), Ratcliffe showed that the rms line-of-sight velocity of the ionospheric irregularities would be :

$$v_0 = \frac{\lambda |\bar{v}_\tau|}{8\tau\tau} \quad \text{(vertical incidence)} \qquad \ldots \quad (9)$$

Computing the value of the ratio, $\frac{|\bar{v}_\tau|}{\bar{\tau}\tau}$, (which has been termed the "speed of fading") from the fading records the rms line-of-sight velocity of the ionospheric irregularities can be determined with the help of (9). Following Booker, *et al* (1950), the value of v_0 can also be obtained from the auto-correlation function, $P_n(\tau)$, of the fading record. As we have not incorporated the analysis of the fading observations by the auto-correlation method, the theory of the auto-correlation method has been left out.

EXPERIMENTAL ARRANGEMENTS

The pulse-transmitter used in this investigation delivers a peak power of 8 KW and is fitted with a 833-valve in cathode-pulsed configuration. This pulse-duration can be varied from 50 to 200 microseconds and the repetition frequency is 50 c/s. The working frequency has a range from 1.5 to 12 Mc/s covered in six bands. The receiver is a modified Hammerlund, in which the band-width has been increased to 30 kc/s with sensitivity slightly improved. A ground-pulse suppressor has been incorporated as had been suggested by Mitra and Roy (1951). The response of the receiver has been made linear over a large dynamic range. The horizontal dipoles fed by co-axial cables have been used both for transmission and reception. As has already been mentioned, for suppressing one or the other of the two magneto-ionic components of the downcoming radio wave, the selective aerial system of Ratcliffe and White (1933) consisting of a pair of crossed loop has been used with the receiver. The experimental arrangement for the suppression of one or the other of the two magneto-ionic components (supposed to be circularly polarised) is shown in fig. 1. The output of the selective aerial system has been fed into the receiver by means of co-axial cables preceded by a transistorized

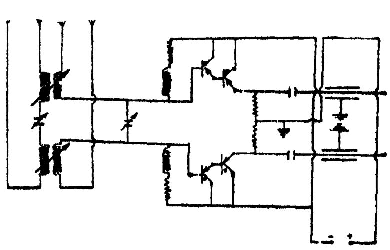

Fig. 1. Polarization arrangement with a pair of crossed loops.

impedance-matching device as shown in the figure. This arrangement has also helped to improve the signal-to-noise ratio in the receiver.

The video output from the receiver has been intensity-modulated by a suitable gate-generator locked in phase to the transmitter pulse. The gate-generator consists of three stages of mono-stable multi-vibrators arranged in cascade so that the variable time and the width of the gate-pulse have been made available over a wide range.

The recording oscilloscope was assembled in the laboratory using B16522 cathode ray tube with bluish white phosphor. The records have been taken on a moving film Cossor Camera at a film speed of 0.2 inch per second.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The study of the sporadic E-region at different hours of the day and the night and at various frequencies has shown the blanketing type as well as the q-type E_s. The number of their occurrences has indicated clearly a preference for the summer and the rainy season. Though no regular routine measurements of the top frequencies or the cusp frequencies have been made, the wind-type of E_s, whose top frequency has been found to vary rapidly with time during the evening hours, has also been observed.

Working with an unpolarized receiver, i.e., using a horizontal dipole aerial with the receiver, a distinct double splitting of the sporadic E-trace on the moving film has been occasionally observed, both for the first order and the second order echoes. A few records have also shown an additional trace.

Fig. 2(a) illustrates a typical fading record showing a single unresolved trace of the E_s-echo, both for the first order and the second order echoes, as depicted on the upper and the lower halves of the record respectively. In fig. 2(b) is given a fading record which has shown a double trace on the moving film for both the first and the second orders. Fig. 2(c) illustrates a fading record which has shown an additional trace in the sporadic E-region for first and the second orders of reflection. The single trace of E_s in fig. 2(a) is due to the reflection of the unresolved magneto-ionic components from the sporadic E-region. When, however, the two magneto-ionic components are resolved and separated from each other, a double trace may be expected from the sporadic E-region. But such splitting may not always be possible, as the E_s-layer is very thin. The observed double trace shown in fig. 2(b) should therefore be attributed to the occasional existence of a double layer in that region. The partial reflection from the double layer would necessarily give rise to the double trace observed on the moving film. Of the three traces shown in fig 2(c), the undulatory trace at the top appears to indicate interference between the two unresolved magneto-ionic components under conditions of gradually changing electron-density in that region or below, giving rise to a rhythmic or periodic fading. The other two broad traces in fig. 2(c) point to the existence of two more layers in the region on very rare occasions.

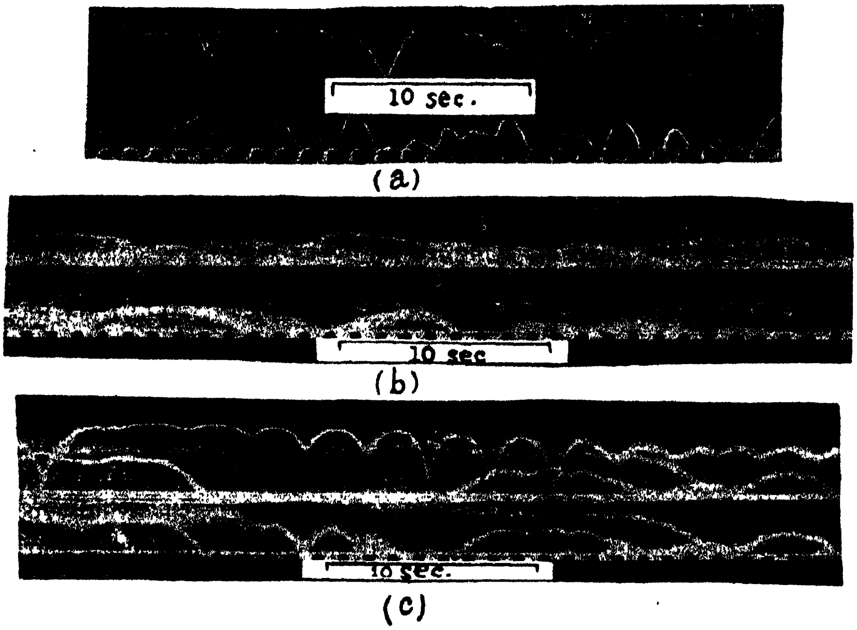

Fig. 2. (a) Fading record showing the usual single trace on the moving film for the first order and the second order echoes from the sporadic E-region on frequency 2.7 Mc/s. Date : 4-7-66, time : 2015 IST.

(b) Fading record showing the double trace on the moving film for the first order and the second order echoes from the sporadic E-region on frequency 3.2 Mc/s. Date : 22-11-65, time : 1951 IST.

(c) Fading record showing the triple trace on the moving film for the first order and the second order echoes from the sporadic E-region on frequency 3.2 Mc/s. Date : 22-11-65, time : 1833 IST.

(The first-order echoes are at the top and the second-order echoes are at the bottom of the moving film. Rhythmic or periodic fading of magneto-ionic origin can be seen in some parts.)

In this connection, it should be mentioned that the ionogram and the electron-density profile for a night flight over Ft. Churchill, Manitoba, Canada, incorporated in the paper by Seddon (1922) showed two or more electron-concentrations in the sporadic *E*-region of the ionosphere. The same paper also illustrated two concentrations in the electron-density profile at noon over New Mexico, U.S.A. and at night over Woomera, Australia. There is thus some experimental evidence in support of the existence of two or more electron-concentrations in this region which would cause a double (or triple) trace on the moving film.

Statistical studies of the amplitude of the signle downcoming wave, obtained by using the selective aerial-system connected to the receiver, have been made from a large number of fading records. The analysis has shown that the Rayleigh and the Rice types occur usually during the noon and the afternoon hours. During the morning, evening and early night hours, when usually reflection occurs from the sporadic E-region other types of amplitude distribution have been observed. Of the other types the most frequent type is the double-peak type or the so-called M-type. The types which have been less frequently observed show (i) an irregular distribution, (ii) a half-gaussian distribution and (iii) a log-normal distribution. In fig. 3(a) are shown two typical Rayleigh types of amplitude distribution for (i) $b = 0$ and (ii) $b = 0.707$. Fig. 3(b) shows a typical Rice distribution for $b = 1.4$. When $b > 3$, the distribution becomes Gaussian as is shown in fig. 3(c). The theoretical distribution is shown by the continuous line, whereas, the experimental points are indicated by black dots. The three amplitude distribution

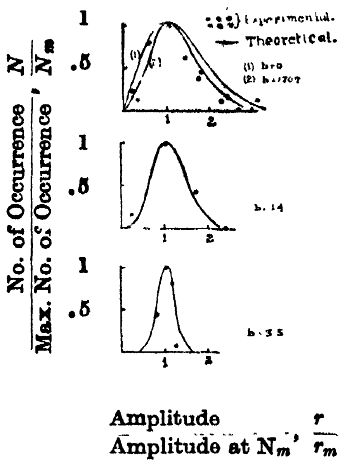

Fig. 3. (a) Rayleigh-type amplitude distribution (normalised) for $b = 0$ and $b = .707$ on 2.9 Mc/s. Date : 28-11-65, time : 0215 IST.

(b) Rice-type amplitude distribution (normalised) for $b = 1.4$ on 2.5 Mc/s. Date : 9-8-63, time : 1830 IST.

(c) Gaussian-type amplitude distribution (normalised) for $b = 3.5$ on 2.9 Mc/s. Date : 28-11-65, time : 0215 IST.

curves, each showing a double peak are illustrated in figs. 4(a), 4(b) and 4(c). An irregular type of amplitude distribution is shown in fig. 5(a), while a half-gaussian distribution is illustrated in fig. 5(b). The log-normal distribution of amplitude is shown in fig. 6(b) which corresponds to the actual amplitude distribution curve shown in fig. 6(a).

The number of maxima in the fading pattern per minute has been calculated and is found to vary between 2 and 5 at normal working frequencies (2.5—5 Mc/s), increasing almost linearly with the wave-frequency. Such linearity had been reported earlier by Skinner and Wright (1957).

The ν_r-distribution has been obtained for the various types of amplitude distributions. This distribution has been found to be Gaussian for the

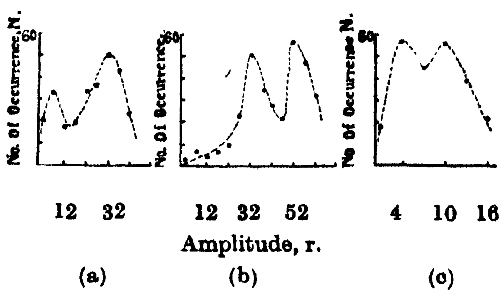

Fig. 4. (a) M-type distribution (first order) on 4.2 Mc/s. Date : 8-7-66, time : 1635 IST.
(b) M-type distribution (first order) on 3.1 Mc/s. Date : 8-7-66, time : 1735 IST.
(c) M-type distribution (second order) on 3.1 Mc/s. Date : 8-7-66, time : 1735 IST.
(The amplitudes are in arbitrary units.)

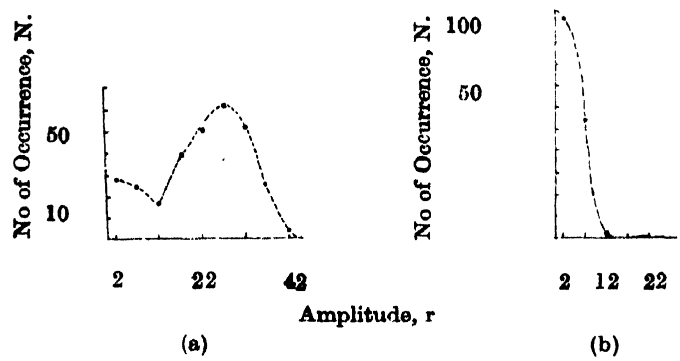

Fig. 5. (a) Irregular-type distribution (first order) on 2.9 Mc/s. Date : 3-12-66, time : 0710 IST.
(b) Semi-Gaussian distribution (first order) on 2.5 Mc/s. Date : 9-8-63, time : 1830 IST.
(The amplitudes are in arbitrary units.)

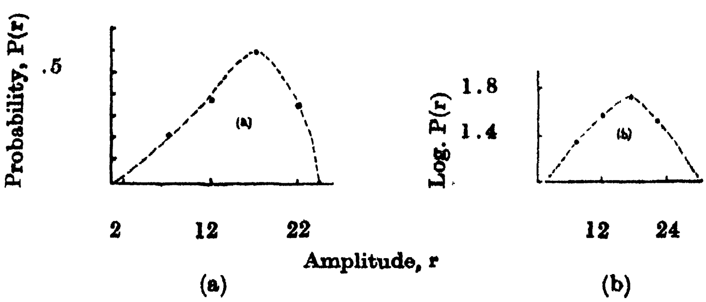

Fig. 6. Log-normal distribution shown in (b) and the corresponding amplitude distribution (first order) shown in (a) on 2.5 Mc/s. Date : 9-8-63, time : 1830 IST.
(The amplitudes are in arbitrary units.)

Rayleigh type of amplitude distribution. For the other types of amplitude-distribution, the v_τ-distribution has been found to correspond to the Pearson type VII distribution. These are illustrated in figs. 7(a) and 7(b). The values of the rms line-of-sight velocity v_0 of the irregularities in the sporadic E-region, as computed from the v_τ-distributions shown in figs. 7(a) and 7(b) with the help of

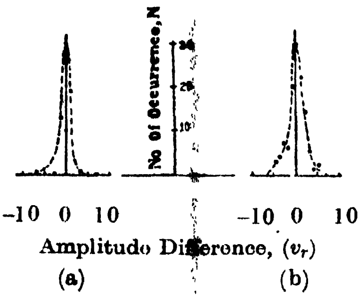

Fig. 7. (a) v_T-distribution (first order) on 2.9 Mc/s. Date : 28-11-65, time : 0215 IST.
(b) v_T-distribution (second order) on 2.9 Mc/s. Date : 28-11-65, time : 0215 IST.
(The amplitudes differences are in arbitrary units and $\tau = 0.215$ sec.)

(9) have come out to be 1.1 m/sec. and 8.6 m/sec. respectively. In computing v_0, the average amplitude-difference $\bar{v}_\tau$ and the average amplitude $\bar{r}$ are expressed in the same arbitrary units. The data for determining v_0 are given below :

$$f = 2.9 \text{ Mc/s}, \quad \lambda = 103.45 \text{ metres}, \quad \tau = 0.215 \text{ sec.},$$

$$\bar{v}_\tau = 0.7 \text{ and } \bar{r} = 37.4 \text{ for the first order echo (fig. 7a)}$$

$$\bar{v}_\tau = 1.82 \text{ and } \bar{r} = 12.75 \text{ for the second order echo (fig. 7b)}$$

The interpretation of the double-peak amplitude distribution will be discussed elsewhere. This is most likely associated with the double layer observed in the sporadic E-region.

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